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Johnsville, Warminster, Pennsylvania

REPORT NO. NADC-AC-6904 3 MARCH 1969

GUIDE TO AIRCRAFT IN-FLIGHT CAMOUFLAGE

FINAL REPORT
AIRTASK A32-523-013/202-1/F020-03-01
WORK UNIT 13-7

PREPARED BY

APPLIED PSYCHOLOGICAL SERVICES, INC.
SCIENCE CENTER
WAYNE, PENNSYLVANIA

Johnsville, Warminster, Pa 18974

DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

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Principles related to aircraft visibility are defined and described. Then a series of steps is suggested to cover systematically these factors as they should be considered in selecting an aircraft camouflage scheme so that the scheme will be effective for local conditions. The effectiveness of various camouflage schemes under various conditions of use is discussed.

Prepared by: A. SIEGEL and D. FLETCHER (Applied Psychological Services, Inc.); J. LAZO and E. GIFFORD (Naval Air Development Center, Aerospace Crew Equipment Department - formerly Aerospace Crew Equipment Laboratory) under contract N00156-67-C-2011.

Reviewed by: _____
E. HENDLER, Ph.D., Manager
Life Sciences Research Group, ACED

Approved by: _____
W. L. GOLDENRATH, CAPT, MSC, USN, Dir
Aerospace Crew Equipment Department

PREFACE*

This handbook provides information which will help in understanding the considerations involved in the design of concealment camouflage schemes for Naval and Marine Corps aircraft. The intent is not to provide camouflage schemes. Indeed, effective concealment camouflage varies with a large number of conditions, many of which cannot be predicted in advance. However, by setting the conditions under which camouflage may be effective into focus and by suggesting camouflage considerations for these conditions, we hope to provide a tool which will help in meeting camouflage requirements.

The first chapter of the text outlines principles related to the visibility of aircraft. These principles define the criteria for selecting aircraft exterior finish schemes to produce lowered aircraft visibility. In the second chapter, a systematic series of steps is suggested to cover the various factors that should be considered in selecting an aircraft camouflage scheme that will be effective for local conditions.

An aircraft's external paint scheme is but one aspect of many factors which contribute to its visibility. If a paint camouflage scheme is decided on, it should be used with these alternative measures, either at the same time to reduce the resultant visual range of the aircraft or at different times to broaden the range of conditions under which the aircraft is effectively camouflaged. For example, under very many conditions, maneuvering can reduce an aircraft's visual range more than a paint scheme can, but painting plus maneuvering can reduce the visual range more than either measure used alone. Or, extensively camouflaging, without using a smoke repressor in fuel, may merely be working in opposite directions.

* Persons who are interested in a more extensive treatment of principles of visibility are referred to the first report of the current program: Literature Survey - Visual Data Relevant to Aircraft Camouflage, NADC-AC-6806, October 1967.

In using a camouflage scheme, it is also necessary to take into account the fact that evidence of an aircraft's presence may be given by other cues, not related to its paint scheme. These other cues include smoke trails, ground shadows, glare from high gloss surfaces, noise, and the use of electronic and photographic detection devices.

Camouflage, like any other passive defense measure, will probably be useful if used for the purpose for which it was designed. If its purpose is not understood, camouflage may give a false sense of security and, as a result, do more harm than good.

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CHAPTER I

PRINCIPLES OF CAMOUFLAGE

Visual detection and visual recognition of an aircraft by a hostile observer may constitute a threat to mission success, at certain points or during certain intervals of modern military missions. Therefore, for many missions, the probability of mission success can be increased by changing the aircraft's surface characteristics so as to decrease the probability that an observer will be able to discriminate the aircraft from its background. The relationships that state how aircraft visibility varies with changes in certain independent factors may be called the "principles of camouflage."

The practical and ultimate criterion of the effectiveness of an aircraft camouflage scheme is the extent to which it influences attainment of mission objectives. More readily obtained measures are more useful in the discussion of camouflage principles. For example, criteria which may be used to evaluate the effectiveness of camouflage include: the frequency, in a number of trials, with which the camouflaged object is seen, the average time required to see the object, or the average distance at which the object is just visible (the visual range).

Three general classes of independent factors affect the range at which an observer can discriminate an aircraft from its background. The first class of independent factors involves area-time considerations. The second class of factors concerns the color of the aircraft, its background, and the illumination conditions under which both are viewed. The third class considers the state of the observer(s) and includes highly complex factors. These classes and the factors within each class are "independent" chiefly in the sense that they produce significant, separable, and estimable or measurable effects on an object's visual range. However, aside from the color of the aircraft, few of these factors can be practically controlled during operations. Within the color of the aircraft, including its brightness, hue, and saturation, we note that:

> *changes in the brightness of the aircraft produce the greatest effect on the range at which an aircraft will become visible.*

Area and Time Factors

Area factors that may affect aircraft visibility include the size of the field which must be searched by the observer, the size of the aircraft, and the distance of the aircraft from the observer. Time factors include the time available for search, and the time the aircraft is exposed. Area and time factors combine in another set of important determinants of aircraft visual range--aircraft displacement, velocity, and acceleration.

The size of the field to be searched and the time available for search are important field factors which influence detection by hostile observers. A scheme which makes an aircraft visible at about twelve miles to an observer, who is informed of the bearing and time of approach, can be expected to make the aircraft visible at about half of this range to an observer, who is actively searching for the aircraft, but who is not informed of where to search for it. Area and time factors are not subject to control by surface camouflage measures, although they may be made more favorable by other measures. Examples are maneuvering to approach the observer from an unexpected direction or increasing aircraft's speed to reduce the time that the aircraft is in the search area. The observer's training in proper scanning measures and the possible number of observers will significantly affect the range at which an aircraft will be detected. A group can improve their corporate visual capability by assigning different persons to search different areas, for example.

Optical aids, such as binoculars and telescopes, may either aid or handicap an observer. These aids often are detrimental to search, because they restrict the area that can be searched at one glance. However, they may be useful for detection under a limited range of adverse viewing conditions. Also, magnifying optical aids may be useful for identification, once a target has been located. Other optical materials interposed between the observer and the aircraft will, usually, handicap his capacity to detect or identify an aircraft, either due to brightness loss and/or color shift caused by the transmission characteristics of the material or due to distortion caused by the optical quality of the material. Special colored filters --for example, yellow filters--for "breaking" camouflage schemes have been found not to improve detection in the field, probably due to these factors.

The relative movement of an aircraft, as compared to its background and to other stable objects in the search area, is important in detecting, identifying, and making estimations concerning the aircraft. Although observers are very poor in making absolute movement judgments, they can make very fine judgments of relative movement. It should be assumed that a stationary aircraft that appears well camouflaged will be less well camouflaged when it is moving. This is especially so when the aircraft's background provides stable reference points against which the aircraft's movement can be judged. Many aircraft backgrounds are relatively uniform; the most important exception is a ground background.

Aircraft size and distance are major determinants of the range at which an aircraft can be seen. While the pilot is not responsible for the size of the aircraft he flies, he may be able to maneuver the aircraft so as to present to a potential observer the smallest aspect of the aircraft. An aircraft which is visible when its greatest dimension is presented to the observer may not be visible when its smallest dimension is towards the observer.

The observer's judgment of the size of the aircraft and the size of certain of its details is important in identifying the aircraft and in making certain estimates concerning the aircraft, for example, its size, distance, altitude, speed, and the like. Training of observers may reduce size and distance illusions but their size and distance judgments will not be accurate unless the visual field includes usable reference objects against which comparisons can be made.

Color and Illumination

The contrast between an aircraft and its background may be defined in different terms. Internal contrast compares a detail of the aircraft with the background formed by the aircraft's surface. External contrast compares the entire aircraft with its land, sea, and/or sky background. Color contrast refers to a comparison of the hue of the aircraft and the hue of the background. Brightness contrast refers to the aircraft-to-background brightness comparison.

For aircraft camouflage purposes, the most important of these contrasts are external contrast and brightness contrast. At the usual viewing distances, internal contrasts are relatively unimportant since most of the aircraft details are too small to be resolved and are, therefore, important only in contributing to the average brightness of the aircraft as a whole. Also, at these distances, the aircraft is seen as colorless because of the dilution of color by the atmosphere between the aircraft and the observer. Therefore:

reduction of external brightness contrast is the most important factor in decreasing an aircraft's visual detection range.

Since the aircraft's brightness is a product of the reflectance of the aircraft's external paint and the illumination on the aircraft's surface, this involves selecting a paint whose reflectance matches, as closely as possible, the reflectance of the aircraft's background, assuming the same illumination on both the aircraft and the background.

Of course, if the camouflage goal is to avoid identification at closer ranges, color contrast and internal contrast may be important. Also, at any viewing range, when the brightness contrast between the aircraft and its background has been reduced to a very low level by camouflage schemes or by other conditions, such as the illumination on the aircraft, then, the color of the aircraft, its internal contrast, and its size are the remaining determinants of its visual detection range.

Other things being equal, the lighting conditions will determine the actual value of visual range for a given aircraft-to-background contrast. When the aircraft and the background are receiving the same illumination, these factors can be ignored, since the contrast value is not affected. As illumination becomes less diffuse, special problems are raised. For example, glare from polished or high gloss aircraft surfaces may affect detectibility. Similarly, when high brightnesses, including the illumination source, are part of the background, the necessarily high resultant aircraft-to-background

contrast is unfavorable for aircraft camouflage. For example, the background brightness is greatly increased when the sea background includes the glitter path of the sun or moon. Another frequent special example occurs when the aircraft target is between the observer and the effective illumination source so that the aircraft is backlighted; that is, the aircraft is seen in silhouette and is, therefore, highly visible.

Observer(s) State

In general, in designing camouflage, the state of the observer should be assumed to be ideal. Since this is rarely the case under the pressures of wartime, this assumption can act as a safety factor in design. Less than ideal observation conditions serve to decrease the range at which an observer will be able to see the target.

The use of optical aids and other optical materials was discussed, above, under area and time factors. In the same section, the effect of special information, such as military intelligence, was also mentioned. The effect of the observer's expected point of view and range are discussed in the second chapter, along with a description of other conditions, which vary with these factors.

Other special observer states, resulting from drugs, fatigue, or other stress factors, lack of training or skill or experience, failure to adapt to the prevailing illumination level before searching, and the like can be expected to deteriorate the observer's visual capacity.

CHAPTER II

SELECTION OF CAMOUFLAGE SCHEME

This chapter lists and discusses the steps to be taken in selecting an aircraft camouflage scheme. First, it is necessary to decide whether surface camouflage will materially improve the probability of mission success for particular aircraft. Second, the details of the surface camouflage scheme must be designed. Third, it is necessary to test whether the scheme, as designed, will contribute to mission performance. A selection process such as this should be carried out by persons who understand local conditions because:

> *no single camouflage scheme can be effective for all conditions.*

Assessment of Need for Camouflage

The need for an aircraft surface camouflage scheme can be established by answering the following questions:

- For the aircraft (or for a group of aircraft to be treated alike) and for their currently assigned mission(s), what phases involve a low visibility requirement?
- For each phase with a low visibility requirement, what is the level of importance of the low visibility requirement--low, moderate, or high?

For all but the simplest cases, it may be useful to tabulate the answers to these questions, as in the following example:

Aircraft Type(s):_____ Squadron(s):_____

Brief description of mission and phase	Low aircraft visibility required			Importance of low visibility requirement		
	Yes	?	No	Low	Moderate	High
(Mission A, Phase 1)			X	-		
(Mission A, Phase 2)		X			-	
(Mission A, Phase 3)	X					X
(Mission B, Phase 1)	X					X
(etc.)						

If this were a description of the whole situation, the tabular description is readily interpreted as showing a need for aircraft camouflage.

Visibility level requirements may be diverse for the different tasks performed by one aircraft squadron at one location for several months. Aircraft visibility can be expressed in many ways. One working scheme is given below:

Aircraft Visibility Level	Illumination Conditions	
	Day	Night (starlight)
High or highly visible	30 to 40 miles	8 to 10 miles
Moderate or moderately visible	10 to 15 miles	2 to 3 miles
Low or barely visible	1 to 2 miles	200 to 1000 yards

Under certain conditions, high aircraft visibility may be required, for example, in being spotted by friendly search and rescue forces when downed and disabled. Under other conditions, moderate visibility may be required, for example, for in-flight refueling. Usually the requirement that the aircraft be barely visible occurs to avoid hostile observation. It is for this requirement that camouflage is usually designed.

The need for camouflage depends on the pattern of visibility levels and of their associated importance levels, over all aircraft tasks. The need for camouflage can probably be established if one of the following patterns of conditions apply:

- The aircraft is assigned to a single, highly important task for which there is a low aircraft visibility requirement and a high level of importance in meeting this requirement.

- The aircraft is usually assigned to one primary mission or the aircraft's tasks involve relatively constant conditions, and it is moderately or highly important that the low visibility be met.

- The aircraft is flexible in its operations or is a multi-mission aircraft. Over different missions and tasks, the need for low visibility varies. However, it is moderately or highly important that the low visibility requirement be met for those tasks for which it occurs.

The first of these patterns would apply rarely and only for extremely vital missions or tasks within a mission. With temporary paints, a camouflage scheme could be applied immediately before the mission and removed immediately after the mission. Although these cases occur rarely, in wartime they do occur and are usually raised without much lead time. Therefore, an aircraft exterior finish scheme for a vital mission may be designed and applied in the field.

The second pattern, referring to an aircraft with one primary mission, is another simple case from the point of view of an effective exterior finish camouflage scheme. When conditions are relatively constant, it is possible to select a scheme of exterior paints that will reliably produce low visibility. The use of an Arctic concealment scheme is an example.

More often, exterior finish schemes are designed for multi-mission or multi-task aircraft. It is easy, away from the complex and changing needs in the field, to treat an aircraft as a primary mission aircraft when it may, in fact, be used in the field for different tasks, each with a different visibility requirement. Working on the drawing board, there is a temptation to design a scheme of "average" effectiveness--a scheme that considers different visibility requirements but meets none of them adequately.

Only in the field can an aircraft's current actual task assignment be stated, giving an accurate set of criteria for design.

Determination of Local Viewing Conditions

The first step in designing the details of a camouflage scheme is to determine the conditions under which the scheme will be viewed --the observer's point of view, the aircraft position, the background characteristics, and the illumination conditions. Essentially, a camouflage scheme is designed so that the aircraft surface viewed by the observer matches the background against which the observer sees the aircraft and so that this match holds under the prevailing illumination conditions. Therefore, there is no substitute for careful observation or prediction of the actual local viewing conditions for which the camouflage scheme is being designed.

The type of background against which the aircraft is viewed is, of course, determined by the point of view from which the observer sees the aircraft. Sky, sea, or terrain backgrounds should be considered, depending on the observer's point of view. An observer may view the aircraft from above and, therefore, see its top surface against a sea or a terrain background. The bottom surface of the aircraft may be viewed from below against a sky background. The side aircraft surface may be viewed against various combinations of sky, sea, and terrain backgrounds. Of course, the attitude of the aircraft with respect to its backgrounds should be taken into account. The examples, above, assume the simplest case of straight and level flight.

Sky Backgrounds

Sky backgrounds are more complex than appears to be the case in casual viewing. The truly blue sky seen on a clear day becomes increasing neutral in hue with increased haze or reduced illumination. For most conditions, the hue of the sky is adequately described as neutral or gray.

On the other hand, the brightness of the sky varies over at least eight logarithmic units. Among the factors which cause the brightness of the sky to vary are the time of day, kind of illumination source, inclination angle of the illumination source, cloud conditions, part of the sky viewed, and the altitude of the observer.

Generally, the sky, even on moonless nights, is the brightest element in the natural environment. Exceptions include the sun, moon, some clouds, the sunlit upper surfaces of aircraft, and the bottom surfaces of aircraft flying higher than about 20,000 feet. For the sky background as a whole, the sky is relatively dark on a clear day. As haze increases, the sky becomes brighter and is even brighter under totally overcast conditions.

As for the brightness of different parts of the sky, in clear daylight, the brightest part of the sky is a small area around the sun; the horizon sky is bright, and the zenith sky is relatively dark. As overcast increases, the bright area around the sun increases in size and brightness and other parts of the sky become brighter. With total overcast, the brightest part of the sky is near the zenith and the sky near the horizon is darkest.

This shifting pattern of overall sky brightness and of the relative brightness of different parts of the sky changes, also, with altitude. The zenith sky darkens as altitude increases. At very high altitudes, the overhead sky is very dark or black and the brightest areas are below, except for a small area near the sun. This area near the sun is about 30% brighter at very high altitudes than at low altitudes. As altitude increases, atmospheric density also decreases. Therefore, there is less filtering and scattering of the sun's light.

Because of the variation in brightness of the zenith sky with overcast and with altitude, it is difficult to design undersurface camouflage that will be effective for a wide range of conditions. At 12,800 feet, paint with 100% reflectance would be required to match the aircraft undersurface to the zenith sky; at 18,000 feet, about 58%; at 36,000 feet, about 28%. Since it is doubtful whether matte white paints can be produced with reflectances higher than about 60%, the design of undersurface camouflage is difficult for use below about 18,000 feet. These values are based on clear day conditions. Over increasingly heavy cloud layers, the bottom of the aircraft receives more reflected light from the clouds and may, therefore, be brighter than the zenith sky.

If one considers a side view of the aircraft against a horizon sky background, a similar set of variable conditions exist. On a clear day, the sky near the horizon is very bright. On a lightly overcast day, the horizon sky is still apparently very bright. Around twilight, the horizon sky brightness can vary over a considerable range from very bright to very dark. The sky near the horizon is bright to medium on a clear night with strong moonlight. It is medium in brightness on a clear moonless or starlit night. It is very dark on an overcast moonless or starlit night--the lowest naturally produced light level.

An otherwise effective side or bottom surface camouflage can be rendered ineffective by virtue of the position of the sun or moon. In many cases, an aircraft is illuminated largely from the opposite side from which it is viewed and is, therefore, seen in silhouette regardless of the reflectance of the aircraft surface being viewed. Only in situations where most of the illumination is on the same side of the aircraft as is the observer can effective camouflage be produced by varying surface reflectance. Tests have been made of one way to compensate for this silhouette--placing lights along the aircraft's major construction lines. This camouflage measure has been limited by practical problems, such as power and weight requirements. However, testing has shown that this method may produce effective camouflage, at least for limited conditions.

Sea Backgrounds

Sea backgrounds vary mainly with observer point of view, sea state, cloud states, and other illumination conditions. The extent of variation in sea background brightness is much greater than is ordinarily thought. The range of brightnesses encountered is from black, when the sea is viewed from steeply overhead, to bright or very bright, when a smooth sea is viewed from a glancing angle. This wide range of brightness can occur even under clear sunlit day illumination conditions. The effect of point of view is, generally, that the sea is darker seen from steeply overhead and brighter from glancing angles, with the change in brightness being most rapid near a 45° viewing angle.

Sea state affects brightness, but only two sea states need be considered--smooth and wavy. The smooth sea state occurs rarely except in land-locked seas. The wavy sea state can be taken as typified by a sea state of 2 or 3. The effect of waves and/or wavelets are to minimize the darkness and brightness extremes of a calm, flat sea. For example, a smooth sea seen as black from steeply overhead on a clear sunlit day appears, not black, but only very dark when the sea is wavy; a bright or very bright smooth sea seen from a glancing angle under the same conditions appears of medium brightness when the sea is wavy.

Cloud states affect sea brightness. Overcast conditions occur roughly 20% of the time in an average month. An overcast brightens a day-illuminated sea, but it may darken a moonlit, night sea. Under scattered cloud conditions, the sea background will include a texture of bright cloud reflectances and/or dark cloud shadows, depending on the relative positions of the sun and the clouds. Thus, the sea may not provide a uniform background, even when viewed from a distance.

Additionally, the sea is brilliant or dazzling in the glitter path of either the sun or the moon, for either a smooth or wavy sea background. Clear sunlit or moonlight conditions occur roughly 43% of the time in an average month.

The effect of illumination conditions upon sea background brightness can best be shown for wavy seas (since smooth seas are relatively rare), for clear weather (since overcast weather occurs only about 20%

of the time in an average month), and for different times of day, as below. The very rapid change in brightness at twilight makes this a difficult time of day for designing effective camouflage. The appearance of the sea under various conditions is summarized below:

Illumination Conditions (clear sky, wavy sea)	Point of View	
	Steeply Overhead	Glancing Angle
Sunlit day	Very dark	Medium
Early twilight	Black	Medium to very dark
Mid-twilight	Very dark to black	Very dark
Moonlit night	Very dark	Very dark
Starlit night	Black	Black

Terrain Backgrounds

Terrain backgrounds are less complex than might be thought. The major simplifying factor for terrains is the distance from which the terrain is viewed. With distance, texture variations are less readily resolvable and, therefore, the terrain appears to have a brightness which is roughly a weighted average of the brightnesses of the different colors present.

For top surface camouflage viewed from a short range, the texture of the terrain is important. The grain of the texture is not so important as that there is a texture. A land camouflage scheme which is effective against a light-and-shadow patterned background of deciduous trees would probably not be effective against a relatively untextured cleared glass landing strip, even if the strip and the tree backgrounds were similar in hue and brightness. At a distance, of course, all textures--those of the terrain backgrounds and those of the aircraft's land camouflage scheme--would appear increasingly uniform so that the averaged reflectances of the aircraft and the background surfaces would determine the adequacy of the camouflage.

In general, a major result of increasing altitude above a terrain background is an increase in the apparent brightness of the background. This effect occurs because the field of view increases with altitude and, therefore, the total amount of light reaching the eye from the background increases. Most of the increase of terrain brightness with altitude occurs up to about 20,000 feet. Beyond this, the effect can be ignored.

For example, a terrain reflectance of about 4% at 2,000 feet will change to about 8% at 20,000 feet and to about 9% at 30,000 feet. Therefore, in designing top surface camouflage, the average altitude above the terrain at which an aircraft will fly must be taken into consideration.

Seen from a constant and low altitude, the reflectance of the terrain varies considerably with the type of terrain. Some examples are given below:

Type of Terrain	Reflectance
Average terrain, except barren land	5 to 6%
Barren land	13%
Sand, snow, and salt flats	20 to 40%
Mature or old growth	4 to 10%
New growth	7 to 15%
Dormant or dry growth	15 to 25%
Inland water	7%

The extent of this variation emphasizes the need for actual local estimation of terrain background reflectances.

The same precaution is required for determining the hue of terrain backgrounds. The following colors match the stated terrains:

Type of Terrain	Color Name
Barren land	
Bare rock, shallow mountain soils	Earth brown
Desert, sand, thin mountain soil	Desert drab
Desert highlands and chestnut, lateritic, reddish chestnut, and reddish brown soils	Earth red
Broadleaf deciduous trees, grass, and and other herbs	
Mature or old growth	Field green or shadow green
New growth	Olive green
Dormant or dry growth	Desert drab
Snow, sand, and salt flats	Insignia white

As for all backgrounds, the brightness of terrain backgrounds varies with illumination conditions. The following values suggest the ranges over which terrain brightness varies with time of day, cloud conditions, and type of illumination source.

	Illumination Conditions			
Type of Terrain	Clear Day	Cloudy Day	Strong Moonlit Night	Starlit Night
Average terrain	Very bright	Bright	Dark	
Snow	Very bright or dazzling		Medium	Very dark

Despite these variations in terrain backgrounds, top aircraft surface camouflage is often effective for situations in which the aircraft is viewed from above and seen against a terrain background. This is especially so if local determinations have been made of terrain characteristics and if the variations in these characteristics and in the altitude at which the aircraft flies over the terrain are relatively limited. For example, patrol aircraft, flying missions at a given time of day over specific terrains at fairly constant altitude, can be effectively camouflaged against observation from above by selecting a specific top surface paint.

Specification of Camouflage Scheme Details

This section discusses the details of the camouflage scheme--which paints are used, where they are applied on the aircraft, and how to treat special aircraft surfaces.

The first and most important consideration in designing an aircraft concealment camouflage scheme is to avoid over-camouflage. The design should be kept as simple as possible. To do this, one proceeds from the simplest possible scheme through successive complications. As each possible complication of the scheme is considered --and all possible complications should be given at least brief consideration--it is necessary to check for any adverse effects that may be introduced. As a scheme becomes increasingly complex, the need increases for testing the effectiveness of the scheme before it is put into operation.

> *It has been found in the field that very simple schemes, chosen so that the overall aircraft reflectance matches the background reflectance, produce better camouflage than do poorly chosen highly patterned schemes.*

The progressive considerations in scheme design may be ordered, as follows:

A. Current scheme

B. Overall schemes for broad surfaces

C. Patterning within overall schemes

1. Countershading schemes
2. Background pattern blending schemes
3. Confusion schemes

D. Special treatment of details

1. Treatment of details
2. Variety of schemes
3. Treatment of insignia and markings
4. Treatment of special surfaces

E. Specification of paint color name and color number

A. Current Scheme

The scheme currently on the aircraft should be evaluated as to its camouflage possibilities under local conditions, first, considering the entire current scheme and, second, considering retention in a modified scheme of a part of the current exterior finish. To the extent that the scheme can use the current finish, maintenance demands are reduced and the added weight of paint, applied over the current scheme, is reduced.

B. Overall Schemes for Broad Surfaces

An overall scheme for broad surfaces may be either a one-color scheme, a top and bottom half scheme, or a top, side, and bottom scheme. Which of these alternatives is emphasized will depend on the variety of points of view from which hostile observation is expected and the expected attitude of the aircraft.

C. Patterning within the Overall Scheme

Patterning within the overall scheme is most often planned to produce countershading but may have more complex goals.

1. Countershading schemes may be required for two reasons--to remove internal contrasts or to achieve the desired average apparent brightness of the overall surface. At a distance, internal details, including shadows and highlights, cannot be discriminated as such. However, shadows and highlights will, respectively, lower or raise the apparent overall brightness of the aircraft. To achieve the desired overall brightness, countershading to reduce shadows and highlights may be necessary. A change to an overall paint of lower or higher reflectance may produce the same result, of course. For the closer ranges, shadow and highlight details on the aircraft surface contribute considerably to aircraft identifiability. In this case, there may be no substitute for countershading, but variations in aircraft attitude may considerably decrease the value of countershading.

Countershading consists, generally, of specifying paints darker than the overall paint for normally highlighted surfaces and specifying lighter paints for surfaces normally in shadow. The extent to which the shadow and the highlight paints should differ in reflectance from the overall paint increases with the overall level of illumination falling upon the aircraft. The location of the shadow and highlight paints is determined by the directionality of the illumination. It is more important to correct for light directionality than for light level. Local weather conditions should be studied to decide whether to design for diffuse or for directional illumination conditions. Countershading that is adequate to eliminate the aircraft's natural shadow and highlight pattern for an overcast sunless day will be adequate for an overcast night or a starry moonless light. Countershading which is effective for a sunny day will also be effective for a clear moonlit night.

We note that the configuration of certain aircraft is so complex that they are very difficult to countershade, for example, helicopters with large engine pods. If weather conditions are rapidly changing, a single countershading scheme will have limited effectiveness. Aircraft flight plans may require frequent changes of attitude with respect to the observer and the illumination, thus lessening the effectiveness of one countershading pattern.

2. Background pattern blending schemes have, under certain conditions, served to improve aircraft camouflage. Especially, land camouflage schemes have been used to blend the aircraft into a patterned terrain background. The most important limitation on background blending schemes is the aircraft to observer range. Most often, aircraft are viewed at so great a distance that the details of a patterned scheme cannot be resolved. A second limitation is that, when the aircraft is in motion, it may be more visible because of the scheme.

When a land background scheme is used for an aircraft, it must be designed to match the pattern of a specific terrain at a specific season. The scale of the pattern should be determined by the scale of the background, as it is resolved by the observer considering his range. The same scale of pattern should be used regardless of aircraft size. Of course, preference is given to large-scale patterns, because they are easier to apply.

3. Confusion schemes--schemes which aim to give a false perception of aircraft type or course--are rarely used. These schemes have consisted of creating false perspective, falsifying light and shadow, or changing natural construction lines. Like other patterns, they integrate at a distance into an apparently uniform surface. If extremes of light and dark paint are used to extend the range at which the confusion scheme can be resolved and, therefore, can be effective in its purpose, then the likelihood is increased that a part of the aircraft will be considerably brighter or darker than the background. Hence, the aircraft will be made more readily detectible by reason of this brightness contrast.

If background blending schemes are used, the paints may be located to create aircraft shape distortion or to distort details that are used for identification of that type of aircraft. The nongeometric pattern elements used for land camouflage schemes serve as confusion camouflage in the sense that they create the impression that the object is not man-made. The added step of using surface materials that are rough or garnished to appear natural, as opposed to man-made, has not been found to be feasible for operational aircraft.

D. Special Treatment of Details

Special treatment of details is required in completing the design of any camouflage scheme.

1. Treatment of contours and transitions should be specified. Uniformly painted areas should have irregular outlines, avoiding straight lines and simple curves. The transition from one uniformly painted surface to another should be gradual, not sharp. For aircraft with complex contours, it may be necessary to specify a wide transition range, i.e., a gradual blending of a darker surface into a lighter surface, as is characteristic of natural targets and backgrounds.

2. A variety of schemes is important if many aircraft of one type operate in a single theater. Reconnaissance and intelligence personnel use pattern repetition as an aid. Rigid duplication of patterns may make a group of aircraft more noticeable than it would be if each aircraft was treated with a different variation of a scheme.

3. The advantage to be gained from camouflage treatment of insignia and markings must be weighed against the normal purposes of these insignia and markings. The insignia and markings may be treated in groups--identification, emergency, and maintenance and service markings. For any one group of markings, a variety of means of camouflage should be considered.

In some cases, as governed by the appropriate command, the markings can be removed by full overpainting of the markings or masking material. For example, for short periods of time, the National Insignia may be covered with masking tape which is, then, overpainted as part of the camouflage scheme. The masking material can be removed when the need for camouflage has passed. Of course, this method is not applicable to high performance aircraft on which the tape would not hold. More important, this overpainting method cannot be used for emergency markings, including warning, rescue, and escape markings. At the discretion of the command, certain redundancies in the emergency markings are not needed. For example, only one, instead of two ejection seat warning and instruction markings on each side of the aircraft, may be needed.

When camouflage is needed at some times and legibility at other times, a reversible template may be useful. For example, a template may be made up with a National Insignia in standard form on one side and the camouflage scheme on the other side. The template can be attached with metal screws or quick fasteners or applied as a slip-on panel. A rigid template is not practical when the aircraft surface is not flat. The method is most useful for low-speed aircraft and for situations where a quick change is needed.

Most markings can be blended into the adjacent camouflaged surfaces by using "spatter" overspraying or daubing with a light coat of the camouflage paint. A spray gun is preferable to a paint brush, since with the spray gun the "spatter" effect can be controlled very accurately. The light overspraying camouflage method is suitable when the marking cannot be obliterated but need not be seen at great distances. With this method, the National Insignia and the emergency markings remain readily legible within a range of 100 yards.

Camouflage of insignia and markings can, also, be achieved by modifying the gloss, color, and size of certain markings. In general, large markings should be made with low gloss paints. Small maintenance and service markings can be glossy without impairing camouflage. Size reduction is possible within the range allowed by current insignia and marking specifications. For example, the National Insignia can be reduced to a 10 inch star. This size is consistent with a camouflage scheme. When letters and numbers are reduced to a 6 inch height, they are still distinguishable at 100 yards. Maintenance and service markings can be reduced to half inch heights without impairing their usefulness. For identification markings that must be seen at a distance, larger than normal sized markings can be used where the color of the markings is changed to produce a low contrast with the adjacent aircraft surface. This device may be used, for example, when two or more squadrons are operating the same type of aircraft in the same area and visual identification at a distance is necessary.

The most common method of camouflaging insignia and markings is by color change. The marking color should be selected, primarily, to provide low brightness contrast with adjacent camouflage paints and, secondarily, to provide low color contrast with adjacent areas. Changing normally white markings to lusterless black is applicable in most cases. When the overall camouflaged surface is light or white, a relatively light and desaturated color, such as desert drab, may be used. One or two standard colors for camouflaging markings should be selected, if possible. Also to simplify the camouflage of markings, templates may be made up; these are useful for size and/or color changes.

4. The treatment of special surfaces must be specified in a camouflage scheme. For example, certain surfaces may require protection from camouflage materials.

Glass and plexiglass surfaces are not to be covered with any paint or other surface material because of solvent damage and visibility reduction. Nevertheless, these areas are highly visible to hostile observers. At least when the aircraft is not in use, glass and plexiglass surfaces can be camouflaged with a cover that has been treated to blend into the overall camouflage scheme. The cover can be made of camouflage material or any material which will take the camouflage paints. The cover may, in some situations, require too much time to put in place; covers may be easily ripped or may be subject to high wind damage.

The camouflage of rotor heads, rotor blades, and propellers presents a specially difficult problem, requiring further study. Tolerance and balance changes due to the weight of any applied material, damage to underlying permanent finishes, adhesion of any applied material in operations, and danger to ground personnel due to obscuring tip markings are aspects of these problems. Preferably, these surfaces should be factory painted or dye impregnated

with camouflage colors. By this means, of course, camouflage changes in the field are limited. In a few cases, a part of large unpainted rotor heads can be lightly oversprayed with camouflage paint. However, because of the need to avoid inner close tolerance mechanisms, such application should be performed with great caution. On the ground, covers can be used, subject to the same demands and limitations as were raised in discussing covers for glass and plexiglass surfaces.

E. Specification of Paint Color Name and Color Number

Specification of color name and color number for each paint required by the camouflage scheme is the final step in the detailed design. Standard paints must be used except in special cases. Considerable time is required to put new paint specifications into the supply system. Of course, for field use, the paint must be also available at the time it is needed and in the quantities needed.

If local conditions are such that the desired paint characteristics are not available in standard paints, the desired characteristics may be obtained by patterning or mixing. Mixing should not be undertaken with paints which have an infrared reflectance characteristic, since mixing damages this characteristic. Patterning consists of achieving the desired paint reflectance with adjacent surfaces of different paints which will be seen as having the desired reflectance if viewed from sufficient distance so that the separate paint areas are not resolvable. Each differently painted surface should be large--about ten square feet in area--to reduce application time.

The color names and color numbers available in temporary paints are described in Military Specification MIL-P-6884, Paint, Camouflage, or Temporary Identification, Solvent Removable. If other paints are used, it is not practical to specify their color characteristics by standard test methods. A special field-developed paint panel may be roughly specified by matching it to a panel covered with a standard specified paint. The two panels should be placed side by side so that they both receive illumination from a moderately overcast northern sky at about a 45° angle of incidence. View the panels from an angle of about 90°. Other illumination sources and any bright surfaces should be screened from the inspection area. To remove gloss differences, wet both panels.

Check of Compatibility with Operational and Maintenance Demands

An aircraft camouflage scheme will be useful in the field only if it can be applied, as designed, without raising special maintenance problems and without interfering with operational demands.

First, the proposed aircraft camouflage scheme should be expressed as written specifications to the maintenance crew. These specifications should be reviewed carefully with aircraft maintenance officers to check that they can be followed under field conditions without raising unusual requirements. For example, this review should consider whether personnel, workspace, safety, or time problems will occur. Especially, this review should consider whether the scheme is likely to interfere with protection of the aircraft exterior under anticipated operational and maintenance conditions. Also, consideration should be given to whether the proposed scheme is likely to interfere with aircraft performance or with personnel comfort and safety during operations.

After this review, the written specifications should be tried out in the shop on an actual aircraft. If possible, the designer of the scheme and the maintenance officer should supervise and observe the actual application of the scheme. It is necessary to determine, first, whether the written specifications can be followed with acceptable ease and accuracy by maintenance personnel. Also, at this point, it is possible to correct previously made estimates of materials, procedures, and time required. If the scheme was designed as one to be removed in the field after a short time, it would be important at this step to obtain information as to the ease of removal and the time required for removal. It may be possible, during this trial application, to revise procedures or even to revise the design to reduce time or other requirements.

The final result of this trial application of the scheme should be, first, a final written form of maintenance instructions for applying, maintaining, and removing the scheme for a particular aircraft. Second, corrected and final estimates should be made available as to materials, equipment, and workspace required, amounts of each needed, type of personnel and man hours required, total aircraft down time required, and special precautions to be followed. These instructions and requirements would, now, be finally reviewed to insure that they are consistent with other demands.

Test of Camouflage Scheme Effectiveness

At this step, the extent to which the proposed aircraft camouflage scheme(s) will achieve its purpose is the issue. Tests are run to estimate the effectiveness of the applied scheme. If the results are favorable, the scheme is tried out in operations. Of course, redesign and subsequent retest may be necessary if the test raises a problem that had not been anticipated in design.

> *We note that employing pictures, taken in flight or otherwise, as a test vehicle can be misleading. Dynamic viewing of moving objects will be involved in the operational situation and still photographs do not simulate or portray this situation.*

Tests with Models

While it is preferable to work with the actual aircraft, if possible, a model whose details have been checked against the current modifications of the aircraft may be employed for preliminary design and test purposes. Both model and flight tests are useful in testing because they, respectively, consider static and dynamic points of view of the scheme. In both cases, the proposed camouflage scheme (or alternate schemes) should be compared with the normal paint scheme. Also, in both cases, the local conditions for which the scheme was designed should be represented, including the observer's point of view, the background, and the illumination conditions. Finally, in both cases, special attention should be given to representing in the tests special local conditions under which the proposed camouflage scheme could prove detrimental to successful mission performance.

While reasonably accurate aircraft models are usually available and it is easy to paint and repaint models in a good approximation of the proposed scheme, it may be difficult to prepare adequate scaled backgrounds for the models. Even more difficult to simulate are the lighting conditions and the observer's point of view, at least when these are unusual; and it is often especially for unusual conditions that camouflage is required. It is important that lighting and point of view be simulated with some care. Often, in testing with models, only the aircraft and its background are simulated, leading to inaccurate estimates of the visibility of the treated aircraft under operational conditions.

Flight Tests

Flight tests should be conducted, if possible. In such tests, simulation is, of course, not a problem, but reaching representativ extreme conditions may be difficult. The major advantage of such tests is that only by these means can a measure be obtained of the visual range, in miles or yards, at which the treated aircraft is just discriminable from a given background, under stated illumination conditions, and from a stated observer point of view. The flight plan for the flight tests must direct both the test aircraft and the observer aircraft and/or ground observer. For each determination of visual range, the flight plan direction should state the relative position of test aircraft and observer and their positions with respect to the illumination and background. For each determination, the obtained visual range at which the observer could just see the test aircraft should be recorded, with a description of the illumination and the background at the time that the visual range was determined. Visual range should, of course, be determined for values representing the range of local conditions for which the camouflage scheme was designed. As with the model testing, values should be included in the flight test to check on local conditions under which the camouflage may be inadequate or, even, detrimental.

Redesign

Depending upon the results of these tests, it may be necessary to redesign the camouflage scheme and, then, to retest the new design. When it is practical to go ahead with the use of the camouflage scheme in operations, flight testing should, in a sense, continue.

Operational Use of Camouflage Schemes

The treatment of camouflage as a passive defense measure can lead to misinterpretation of its operational usefulness and, therefore, perhaps, to misuse or, at least, to inefficient use. The pilots who fly the camouflaged aircraft should be fully briefed on the intended usefulness in a particular mission situation of the particular camouflage design.

Primarily, the pilot's understanding of the camouflage scheme is necessary to insure that the camouflage will be used under the conditions for which it was designed. The pilot can affect considerably a scheme's effectiveness by taking advantage of whatever choices he has in flight to bring the aircraft to the position with respect to the observer, background, and illumination for which the camouflage was designed. For example, assume that the top of an aircraft has been painted sea blue, to obtain minimum contrast with a sea background. Since the topside color must necessarily be carried part way down the sides of the airplane, it should be recognized that this already detracts somewhat from the devised camouflage effect, when the aircraft is viewed against a sky background. THIS INCREASE IN VISIBILITY BECOMES GREATLY AGGRAVATED AT LOW ALTITUDES when the aircraft performs evasive maneuvers such as banks and turns, since these movements expose large, dark upper surface areas to view, yielding a most undesirable contrast against a sky background.

Secondarily, the pilot's reports can be treated as continued flight testing of the camouflage scheme. Continuous operational testing of a camouflage scheme is of immediate field use when temporary camouflage paint is available so that schemes can be modified in the field. The briefing of the pilots on the camouflage scheme should include a request that they report to the maintenance officer any special observations, questions, or problems concerning the aircraft camouflage scheme that may have been raised in a flight. This information would provide the designer with more accurate estimates of the visual range of the treated aircraft, with suggestions for design improvements, and with notes of problems that should be considered in scheme redesign or in changing its operational use. A critical reason for continued interest in the effectiveness of a camouflage scheme after it has become operational is that the conditions for which it was designed may, themselves, change. The basic information required for the redesign, then, are pilot reports of the nature of the changed conditions.

Information Dissemination

When aircraft camouflage schemes have been developed and used locally, information on this use might be disseminated to others who might be interested. This information should include: the aircraft, conditions of use, effectiveness in achieving low aircraft visibility, a sketch of the camouflage scheme, special problems raised and their actual or suggested solutions, including both operational and maintenance problems.

Checklist Considerations for Camouflage Scheme Development

Assessment of Need

1. For the aircraft and for each of its currently assigned missions, what phases involve a low visibility requirement?

2. What is the importance of each low visibility requirement?

3. Is a camouflage scheme needed?

Determination of Local Viewing Conditions

1. Against what background will the aircraft be viewed when the low visibility requirement(s) must be met?

2. What is its brightness? What are its hue and saturation?

Specification of Camouflage Details

1. What can be done, with minimum change to the current paint scheme, to match the brightness of the aircraft to that of its background under the anticipated condition of viewing?

2. Will a one color scheme satisfy the need?

3. Will a top and bottom half scheme satisfy the need?

4. Will a top, side and bottom scheme satisfy the need?

5. Is countershading required?

6. Is a background pattern blending scheme required?

7. Is a confusion scheme required?

8. How should contours and transitions between areas be treated?

9. How, if in any manner, should insignia and markings be treated?

10. Is a variety of schemes needed over different aircraft of a group?

11. What, if anything, can be done about special surfaces?

12. What are the specified color names and numbers of the paints needed to meet the requirements?

Check of Consistency with Operational and Maintenance Needs

1. Will application of the scheme interfere with other operational and maintenance requirements?

2. Is the predicted application time realistic?

3. How long is the removal time?

Test of Camouflage Scheme Effectiveness

1. How does the developed scheme compare with the scheme now on the aircraft, when viewed under the conditions for which the camouflage scheme was designed?

2. Are my comparisons based on tests with models? on operational flight tests?

Use and Redesign of Camouflage Scheme

1. Do the pilots who will fly the aircraft understand the conditions under which they can expect the scheme to be effective? ineffective?

2. Do the pilots understand what they can do, in flight, to increase the schemes effectiveness?

3. Have I instituted a method ongoing evaluation and redesign of the scheme?

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13. ABSTRACT

Principles related to aircraft visibility are defined and described. Then a series of steps is suggested to cover systematically these factors as they should be considered in selecting an aircraft camouflage scheme so that the scheme will be effective for local conditions. The effectiveness of various camouflage schemes under various conditions of use is discussed.

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